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Studies on K-electron capture probability in the decay of ^{95}Tc and ^{139}Ce

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Abstract : The electron capture probability measurements were performed in the decay of ^{95}Tc to the 1073.8 and 765.79 keV levels in the daughter ^{95}Mo using a x-γ internal sum coincidence technique for the first time. The experimental P_k values of the transitions were estimated to be 0.868 ± 0.052 and 0.870 ± 0 040 in agreement with the theoretical values 0.879 and 0.880, respectively The P_k value of the allowed transition in the decay of ^{139}La was also measured employing the same technique. The experimental P_k value was found to be 0 714 ± 0 025 in agreement with the theoretical value 0.723.

Keywords : K-electron capture probability, allowed transitions x-γ internal sum coincidence, HPGe system.

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1. Introduction

Studies on electron capture probabilities are not only of interest in Nuclear Science but also in Astrophysics, Nuclear Medicine, Nuclear masses *etc*. We have taken up a systematic programme on these measurements following the x-γ sum coincidence technique proposed by Das Mahapatra and Mukherjee [1]. Our recent results in ^{168}Tm and ^{183}Re were reported by Vara Prasad *et al* [2]. The same paper includes references to our earlier studies. We have employed a similar experimental technique to undertake the present measurements also and followed identical experimental procedures to determine P_K (expt.) values. The

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experimental arrangement essentially consists of a high resolution (220 eV at 5.9 keV of Mn K_α line) HPGe detector coupled to a computer controlled multi channel analyser. The experiments were performed with a source at a distance of 5 cm from the surface of the detector, so as to reduce the detector dead time. The relative efficiency calibration of the system was performed in the usual manner and is shown in Figure 1.

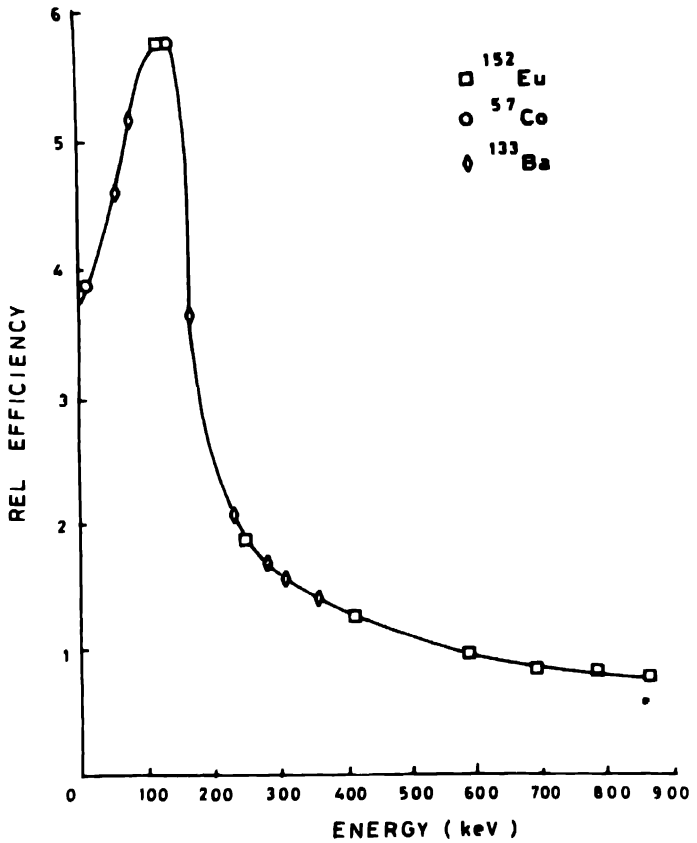

Figure 1. The relative efficiency of the HPGe system.

2. ^{95}Tc ($T_{1/2}$ = 20 h)

A partial decay scheme of ^{95}Tc which is of present interest is shown in Figure 2, taken from Lederer and Shirley [3]. Figure 2 shows that 93% of electron capture decay of ^{95}Tc proceeds to the 765.79 keV level while 4.5% to the 1073.8 keV level. The decay of these levels *via* 765.79 and 1073.8 keV transitions to the lower ones are shown in Figure 2 by wide lines. Both transitions appear to be allowed beta transitions following the spin sequence $7/2^+ \rightarrow 5/2^+$. No previous measurements are available on the P_K values of these two transitions though the other spectroscopic parameters are known. Thus, it is felt worthwhile to undertake the present study on the P_K values in the decay of ^{95}Tc.

The radioisotope ^{95}Tc was produced at the Variable Energy Cyclotron Centre, Calcutta, India *via* ^{92}Mo (α,p) at a beam energy of 15 MeV and current 200 nA. The target

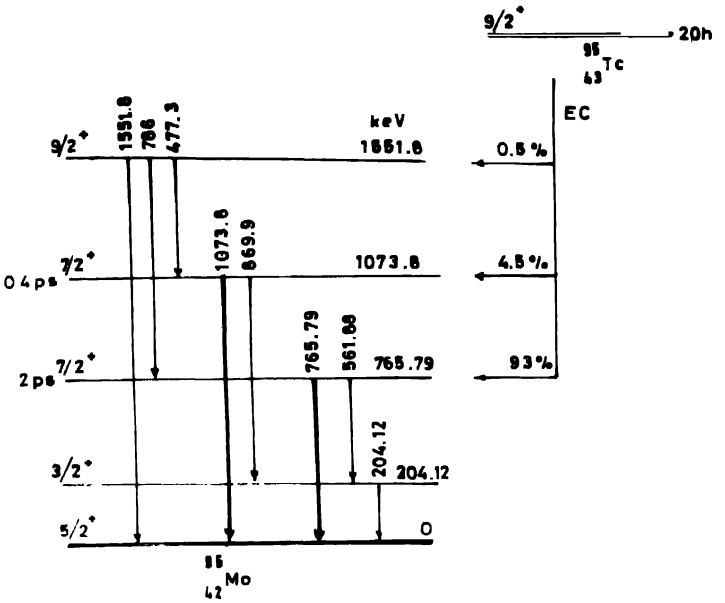

Figure 2. A partial decay scheme of ^{95}Tc.

thickness was 1.2 mg/cm^2. After withdrawing the source from the site of irradiation, a waiting period of about one day was allowed before commencing the data collection to minimize interferences due to short lived activities. The x-γ spectrum was collected using the HPGe (system) and is shown in Figure 3. The data was collected over a time period so

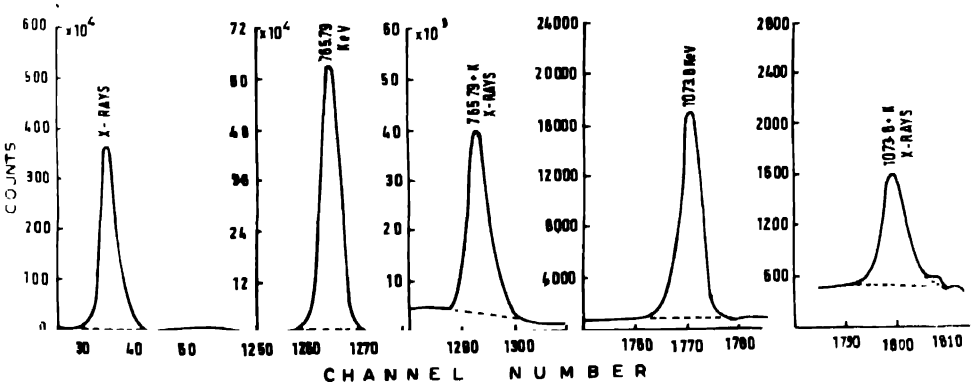

Figure 3. The X-ray, gamma and sum spectrum from ^{95}Tc

as to ensure a good statistical accuracy (< 1%) in singles and $\gamma + x$ sum lines. From Figure 3, it may be seen that the gamma transitions of present interest 765.79 and 1073.8 keV and the corresponding sum lines (γ+K X-ray) show up in Figure 3.

2.1. Computation of the experimental P_k value to the 765.79 keV level :

The experimental P_k value was computed using the following relationship taken from Bambynek *et al* [4].

$$N_{765.79+K} = \omega_k \varepsilon_k \left\{ \frac{I^{786}}{I^{765}} \left[P_k^{1551.8} + \frac{\alpha_k^{786}}{1+\alpha_T^{786}} \right] + P_k \left[1 - \frac{I^{786}}{T^{765}} \right] \right\} N_{765.79} \quad (1)$$

P_k's, α's and I's represent the K-electron capture probabilities, Internal Conversion Coefficients and intensities of the respective transitions respectively, ^{765}T represents the total intensity of the gamma rays decaying from the 765 KeV level, N's represent the intensities of gamma and gamma + K X-ray lines and ε_k is the absolute efficiency of the K X-ray. The intensities of the individual gamma and sum lines were obtained from Figure 3 using the fitting routines after subtracting the linear background. The intensities thus obtained, were corrected for efficiency using Figure 1 and self-absorption (lies within experimental errors). The sum peak intensity was also corrected for chance coincidences. α_T's were taken from Rosel *et al* [5]. In the above equation ω_k, the K-fluorescent yield, was taken from the tables of Bambynek *et al* [6] $P_k^{1551.8}$ is due to the interference from the upper 1551.8 keV level and the $P_k^{1551.8}$ theoretical value was computed using the relationships of Behrens and Janecke [7]. The absolute efficiency of the K X-ray was determined in the following manner.

The spectra of 81 keV and 356 keV reference lines from ^{133}Ba were studied in a separate experiment in an identical geometry. The absolute efficiency of the 356 keV transition was determined with the help of the following relationship.

$$N_{356+81} = N_{81} \frac{}{1+\alpha_T^{356}} \varepsilon_{356} \quad (2)$$

Here, N_{356+81} and N_{81} are the intensities of the sum 356 + 81 and 81 keV lines, respectively and ε_{356} is the absolute efficiency of the 356 keV line. The α_T^{356} value of Rosel *et al* [5] was used in the above equation. A substitution of N_{356+81}, N_{81} and α_T^{356} in eq. (2) gives the absolute efficiency (ε_{356}) of the 356 line. The absolute efficiency of the K X-ray that appears in eq. (1) is related to the absolute efficiency of the 356 keV transition by the following relationship.

$$\left(\varepsilon_k\right)_{abs} = \left[\frac{\varepsilon_k}{\varepsilon^{356}} \right]_{rel} \left(\varepsilon_{356}\right)_{abs} \quad (3)$$

The relative efficiency values of K X-ray and 356 keV gamma transitions were obtained from Figure 1. The values of different parameters that occur in eq. (1) are summarized in Table 1. The different parameters thus obtained, were substituted in eq. (1) to get $P_k^{765.79}$ (expt). The P_k (theory) was also computed using the relatioship of Behrens and Janecke [7]

and the Q_{EC} value due to Wapstra and Bos [8]. The experimental and theoretical $P_k^{765.79}$ values are summarized in Table 2. The compounded error assigned to P_k (expt.) is due to the individual errors in γ-intensities (~ 0.5%), ω_k (4.2%) and ε_k (2%).

Table 1. Values of different parameters used to obtain the P_k (expt) values of the 765.79 keV level and 1073.8 keV level of present interest in the electron capture decay of ^{95}Tc and 165.85 keV level in the electron capture decay of ^{139}Ce.

Nucleus	Parameter	Value
	ω_k	0.764 ± 0 032
	ϵ_k	0.0849 ± 0.0017
^{95}Tc	$N_{765.79}$	2682632 ± 1739
	$N_{765.79+K}$	151420 ± 509
	N_{1073}	165174 ± 605
	N_{1073+K}	9306 ± 349
	ϵ_k	0.1009 ± 0 0020
^{139}Ce	ω_k	0 906 ± 0.026
	$N_{165\,8}$	1696360 ± 1630
	$N_{165\,8+K}$	110718 ± 890

Table 2. Experimental and theoretical P_k values in ^{95}Tc and ^{139}Ce.

Nucleus	Level energy in the daughter (keV)	Transition	P_k value Expt	Theory
	765.79	$7/2^+ \rightarrow 5/2^+$	0.870 ± 0.040	0 880
	1073.8	$7/2^+ \rightarrow 5/2^+$	0 868 ± 0.052	0 879
^{139}Ce	165.8	$5/2^+ \rightarrow 7/2^+$	0.714 ± 0 025	0 723

2.2. *Computation of experimental* $P_k^{1073.8}$:

The experimental value of P_k to the 1073.8 keV level was computed just as in the previous case and with the help of the following relationship,

$$N_{1073.8+K} = \omega_k \varepsilon_k \left\{ \frac{I^{477}}{I^{1073.8}} \left[P_k^{1551.8} + \frac{\alpha_k^{477}}{1+\alpha_T^{477}} \right] + P_k \left[1 - \frac{I^{477}}{T^{1073.8}} \right] \right\} N_{1073.8}, \quad (4)$$

which also includes contribution from the EC decay of the upper 1551.8 keV level.

After applying the usual corrections to the observed 1073.8 gamma and 1073.8 + X line intensities in Figure 3, the final values of gamma and sum peak intensities were determined A substitution of different parameters in eq. (4) has yielded the experimental P_k

value as 0.868 ± 0.052. The errors were estimated just as in the case of P_k of the 765.79 keV level. The theoretical value of P_k was computed to be 0.879. The different values of P_k and the corresponding theoretical values are summarized in Table 2.

Table 2 shows that the present experimental values of P_k agree with the theory. We have also computed the theoretical values using Q_{EC} values due to different mass relationships. We have found that the P_k values are not sensitive to the variation in Q_{EC}. The present value of $P_k^{1073.8}$ is in good agreement with the Q_{EC} value due to Wapstra and Bos [8].

3. ^{139}Ce ($T_{1/2}$ = 137.2 d)

The decay of ^{139}Ce is *via* electron capture to the daughter ^{139}La. It is a simple decay scheme and well studied as shown in Figure 4. The K-electron capture probability was measured by

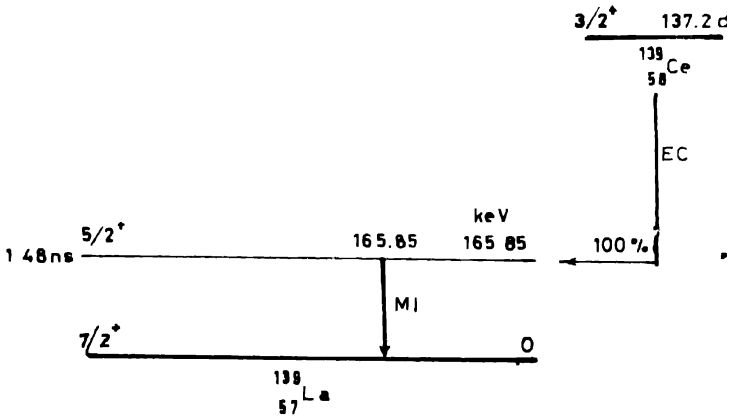

Figure 4. The decay scheme of ^{139}Ce

several authors [3] employing different experimental techniques. However, one sees discrepancies in the P_k values ranging from 0.65 to 0.87. Hence, we felt that it was worthwhile to undertake a remeasurement of the same accurately by using the sum coincidence technique.

The ^{139}Ce source was produced *via* ^{139}La (α, p3n) reaction at a beam energy of 55 MeV and a current of 200 nA at the Variable Energy Cyclotron Centre, Calcutta, India. After allowing a waiting time of one week to eliminate the short lived activities, the experimental data were collected in the same geometry employed for ^{95}Tc. The gamma transition of present interest, namely, 165.8 keV follows the spin sequence of $5/2^+ \rightarrow 7/2^+$ while the corresponding K X-ray energy, a weighted average of K_α and K_β, is 34.18 keV. The gamma and the x-γ sum lines are shown in Figure 5. The final values of $\gamma + x$ sum intensities were determined in the usual manner after applying the necessary corrections. In the case of sum peak intensity, the $5/2^+$ level half-life of 1.48 ns is of no consequence in the

present measurement in as much as the resolving time of the detector system is 2 μs. The $P_k^{165.8}$ (expt.) was determined using the following relationship.

$$N_{165.8+K} = \omega_k \varepsilon_k P_k N_{165.8}. \tag{5}$$

The absolute efficiency of the K X-ray line (weighted average of K_α and K_β) was determined following the procedure given for ^{95}Tc. The different parameters used for the

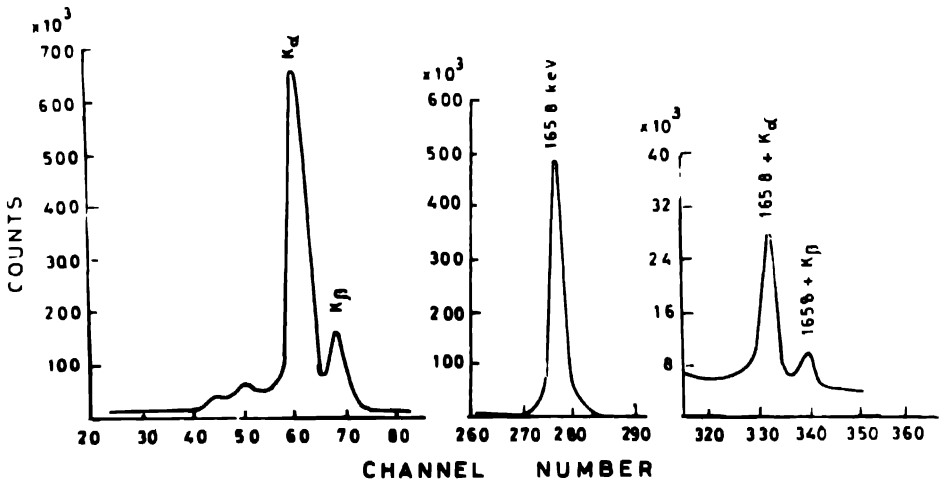

Figure 5. The X-ray, gamma and sum spectrum from ^{139}Ce.

calculation of P_k (expt.) are also given in Table 1. After a substitution of ω_k, ε_k, $N_{165.8}$ and $N_{165.8+K}$ in eq. (5), the experimental P_k value was calculated and is found to be 0.714 ± 0.025. The error to the experimental P_k value is assigned after taking into account the individual errors as mentioned in the case of ^{95}Tc. The P_k (theory) was computed using the Q_{EC} value due to the mass relationship of Wapstra and Bos [8] and the theoretical value thus obtained, is 0.723. These values are included in Table 2. The present experimental value is seen to be in good agreement with the theory due to Behrens and Janecke [7].

4. Conclusions

The experimental values of the electron capture probabilities in the decay of ^{95}Tc and ^{139}Ce are measured using a x-γ sum coincidence method. The relevant transitions following the same spin sequence $7/2^+ \rightarrow 5/2^+$ in the decay of ^{95}Tc to the daughter (^{95}Mo) levels 765.79 keV and 1073.8 KeV are found to be 0.870 ± 0.040 and 0.868 ± 0.052 respectively in agreement with the theory within the experimental uncertainties. The P_k value governing the EC transition ($5/2^+ \rightarrow 7/2^+$) in the decay of ^{139}Ce to the daughter (^{139}La) level 165.8 keV is measured to be 0.714 ± 0.025, consistent with the theoretical value. The present experimental P_k values are seen to be in accordance with the mass relationship due to Wapstra and Bos.

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